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326.—REPORT ON THE WORK OF THE STUDY COMMITTEE No. 8.—OVER VOLTAGES AND LIGHTNING

by

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Comparative tests on spark-gaps

INTRODUCTION

In order to achieve the optimum arrangement for the coordination of insulation and overvoltage protective devices from the technical and economic viewpoint, high accuracy is required in the measurement of impulse voltages. It was for this reason that the C.I.G.R.E. Committee No. 8 decided, at its meeting in Stockholm from 1 to 3 June, 1953, to determine the accuracy which can at present be attained in the measurement of impulse voltages by comparative experiments in a number of high-voltage laboratories in various countries. For these experiments special importance was attached to determining the *technical* measuring accuracy, which is used for industrial measurements and acceptance tests. Artificial methods of improving this accuracy, such as, for example, irradiation of the spark gaps, were deliberately avoided, because although these methods are of course well known to research workers, they are not generally used when making industrial measurements.

The members of the C.I.G.R.E. Committee No. 15 (Coordination of Insulation) also took part in the above-mentioned discussion of the C.I.G.R.E. Committee No. 8.

On the basis of a research programme of 28 October, 1953, the appointed study group communicated the results of tests carried out up to the end of 1955 by 14 European high-voltage laboratories. These laboratories are distributed among the various countries as follows:—

Germany (3), France (1), Holland (1), Austria (1), Sweden (1) and Switzerland (7). A summary showing the laboratories which participated and the tests which they carried out is given in Table I. The results of the measurements were statistically analysed by the Swiss Research Committee for High Voltage Problems (F.K.H.) in Zurich, and were discussed at the meeting of the Study Group on 18 and 19 November, 1955 in Zurich. The results of the measurements made to date are described in the following report.

Tests objects.—The comparative tests were deliberately made on the simplest and most easily reproducible objects possible. For this reason no insulators or overvoltage arresters were chosen, but

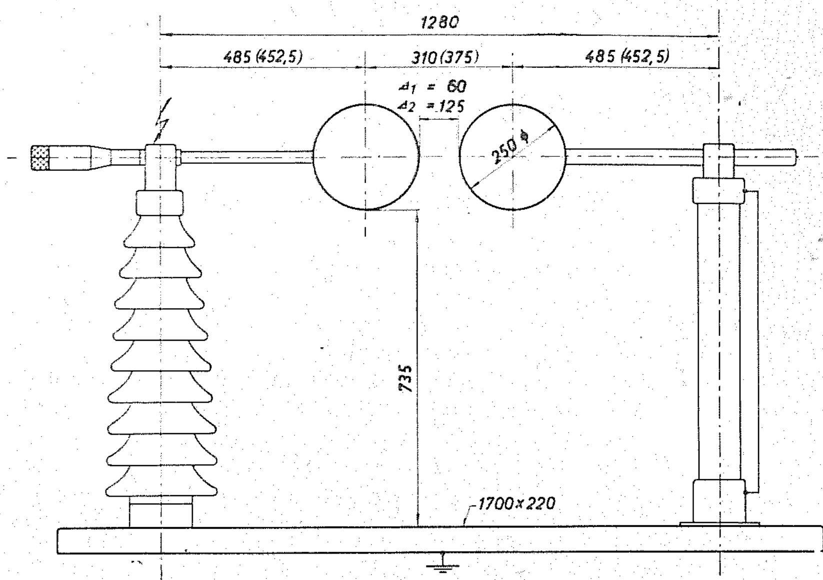

FIG. 1.—Investigated sphere gap, sphere diameter 250 mm; Gap 60 and 125 mm.

provisionally two different sphere gaps, a rod-rod gap and a rod-plane gap. The arrangement of these spark gaps is shown to scale in *figures* 1 to 3. Each laboratory made its own spark gaps from the dimensional drawings.

Laboratory arrangements.—Each laboratory used its own normal equipment. The results, which were discussed at the meeting held on 18/19 November, 1955 in Zurich, showed that it would be desirable to send a questionnaire in order to provide a more accurate description of the overall arrangements used in the laboratories for the tests. The results of this questionnaire are shown in the

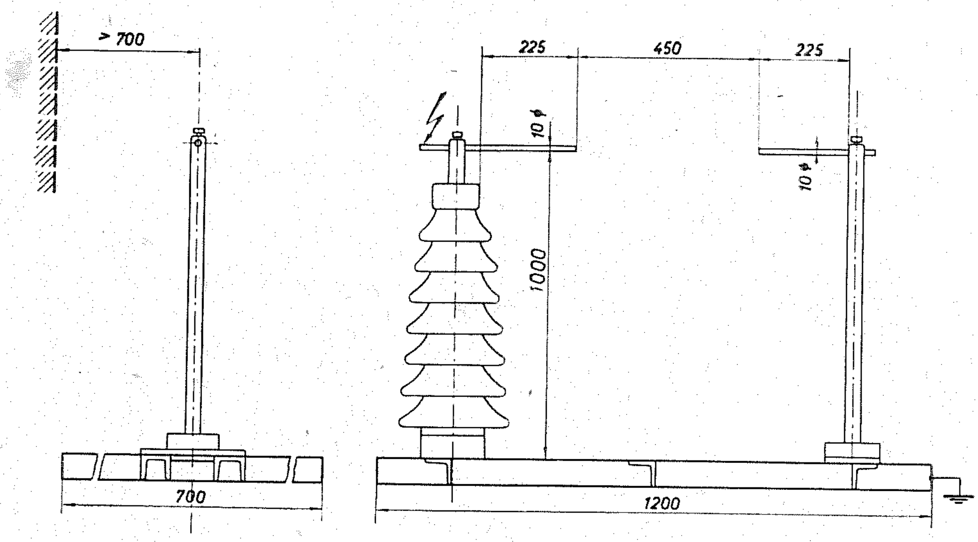

FIG. 2.—Investigated rod-rod gap, spark distance 450 mm.

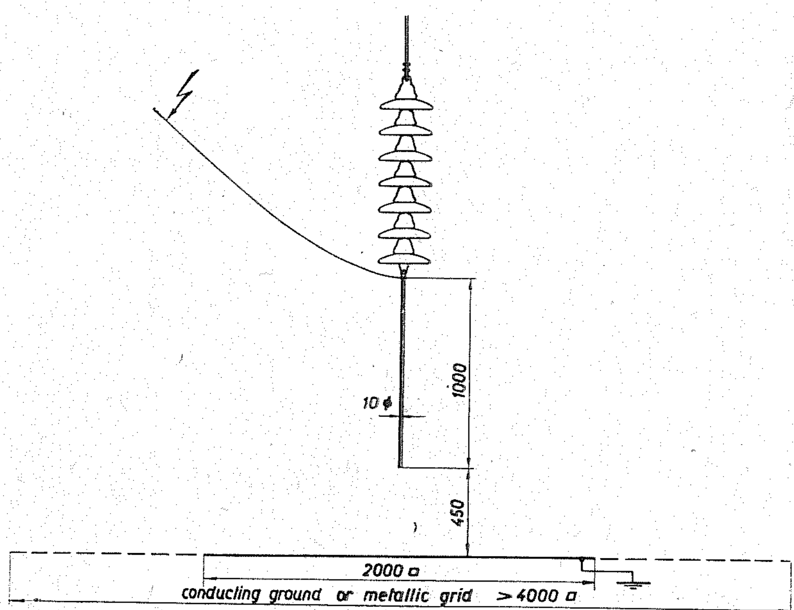

FIG. 3.—Investigated rod-plane gap, spark distance 450 mm.

TABLE I. — Comparative Tests on Gaps.

Summary of the laboratories taking part and the tests which they carried out.

Laboratory and sign letter	Country	50 % flashover impulse voltage																Impulse characteristics															
		Sphere 60 mm				Sphere 125 mm				Rod Rod 450 mm				Rod plane 450 mm				Sphere 60 mm				Sphere 125 mm				Rod Rod 450 mm				Rod plane 450 mm			
		dry		wet		dry		wet		dry		wet		dry		wet		dry		wet		dry		wet		dry		wet		dry		wet	
		+	—	+	—	+	—	+	—	+	—	+	—	+	—	+	—	+	—	+	—	+	—	+	—	+	—	+	—	+	—	+	—
A. A.E.G....	Germany..	x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x			x	x			x	x			x	x		
B. A.S.E.A. .	Sweden ..	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
C. B.B.C. ...	Switzer-land ...									x	x	x	x	x	x	x	x									x	x	x	x	x	x	x	x
D. E.d.F.....	France ...	x	x	x	x	x	x	x	x	x	x	x		x		x																	
E. E.T.H....	Switzer-land....	x	x	x	x	x	x	x	x	x	x	x	x	x		x																	
F. F.K.H. ...	Switzer-land....									x	x	x	x																				
G. K.W. Brugg....	Switzer-land....	x	x							x	x			x	x																		
H. K.E.M.A.	Holland ..	x	x	x	x	x	x	x	x	x	x	x	x																				
J. Langenth.	Switzer-land....					x	x			x	x			x	x																		
K. Micafil ...	Switzer-land....	x	x			x	x			x	x			x																			
L. Sécheron..	Switzer-land....					x	x			x	x			x	x							x	x			x	x			x	x		
M. Siemens-Schuckert	Germany..	x	x			x	x			x	x			x	x																		
N. Stud. Ges.	Germany..	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
O. T.H. Graz	Austria ...	x	x			x	x			x	x			x				x	x			x	x			x				x			

Table II. — Experimental conditions in the various laboratories.

A. *General data on illumination of the test object, clearances and earthing of the test equipment.*

Laboratories	Illumination of the spark gap				Distance between voltage divider and test object			Earthing		
	Daylight	Direct sunlight	Sparks of imp. gen. to be seen from test object	Distance	Length of lead test object to voltage divider	Clearance to nearest external objects	Distance of plate from ground	At various points?	Only one point, at	Measuring apparatus in Faraday cage
				m	m		mm			
A.E.G	No	No	Yes	3.0	2.5	2	0	Yes	—	Yes
A.S.E.A.	No	No	Yes	6.5	2	2	0	Yes	—	No
B.B.C.	Yes	No	No	—	3	5	350	Yes	—	No
E.d.F.	Yes	No	No	—	1.2/1.8	1.8	0	No	Divider	No
E.T.H.	No	No	No	—	1.5	4	0	No	C.o.r.	Yes
F.K.H.	Yes	No	No	—	3	2.7	0	No	Divider	No
K.W. Brugg	Yes	No	Partly	4	1.1	3	0	No	Divider	No
K.E.M.A.	Yes	No	Yes	2	1	1	0	No	Imp. gen.	No
Langenthal	No	No	No	—	5	3	50	No	Imp. gen.	Yes
Micafil	Yes	No	Yes	2.5	2	4	200	No	Divider	No
Sécheron	Yes	No	No	—	2	3	0	No	Divider	No
Siemens	Partly	No	Yes	4	3	3	0	Yes	—	No
Stud. Ges.	Yes	No	No	—	3	3	0	Yes	—	No
T.H. Graz	No	No	Yes	2.75	1.7	1.5	0	No	Divider	No

TABLE III

B. *Data on impulse generators and voltage dividers.*

Laboratory	Impulse Generator						Voltage divider			
	Impulse capacity C_G	C_B total	R_D	R_D distribution	Triggering	Charge voltage measured	Type of Divider	Divider ratio R_2/R_1	Divider ratio C_2/C_1	Shield capacity
	pF	pF	Ω							pF
A.E.G.	19,700	1,100	483.2	In 8 stages of 60.4 Ω	External.	Yes, electrostatic.	*e)* Capacitive divider.	—	1 : 750	—
A.S.E.A. ...	31,000	750	800	100 in imp. gen. 700 outside.	Automatic spark gap irradiated.	No.	*b)* Resistive with shield.	1,000/47 Ω	—	75
B.B.C.	17,500	1,400	400	In 8 stages.	Automatic.	Yes on mains side.	*e)* Purely capacitive.	—	1,000 pF/1 μF	—
E.d.F.	9,400 21,500	500	600	5 × 60 + 300 outside.	Approching spheres.	Yes.	*b)* Resistive with shield.	340	13,400/417 pF	ca 75
E.T.H.	15,000	600 350	1,200 2,100	200 Ω inside rest outside.	Trigatron.	Yes.	*e)* Capacitive divider.	—	180,000/209 pF	—
F.K.H.	83,000	500	820	No.	Automatic.	Yes.	*e)* Capacitive.	—	182,000/464 pF	—
K.W. Brugg.	32,000	1,450	301	6 × 8.5 Ω + 250 ser. res.	Automatic.	Yes.	*a)* Resistive divider.	4,000/50 Ω	—	—
K.E.M.A. ...	20,000	1,100	250	100 in imp. gen	External.	Yes.	*b)* Resistive.	14,500/90	—	75
Langenthal .	3,880	500	1,390	In 16 stages.	Automatic.	No.	*d)* Mixed.	375	375	—
Micafil	59,250	3,200	135	In 8 stages.	Automatic.	No.	*f)* Mixed, special.	412 : 1	412 : 1	ca 1,300
Sécheron....	59,250	3,300	135	In 8 stages.	Trigatron.	Yes.	*d)* Mixed, special.	18,000/23.5 Ω	—	3,200
Siemens	10,000	800	520	6 × 40 Ω + 280 ser. res.	3 sphere gaps.	Yes.	*b)* Resist. I.	551.8	—	—
Stud. Ges...	5,000	400	1,400	500 + 900.	Trigatron.	Yes.	*e)* Capacitive.	—	100/1,700 pF	—
T.H. Graz...	5,000	1,700	310	100 inside. 210 outside.	Trigger gen. and Trigatr.	Yes on mains side.	*a)* Resistive.	4,952/126.1 Ω	—	—

three tables Nos. II to IV. Table No. II contains the general information on the arrangements used for the test, specifications regarding the illumination of the test object, clearances, earthing, etc., Table III data on the impulse generator and potential divider, Table IV data on the cathode ray oscillograph with its connecting cable.

In the *specification of the voltage divider*, the following different arrangements were regarded as possible:—

a) Resistive divider without intentional shield capacity.

b) Resistive divider with a small shield capacity in air, produced by suitably shaping the electrodes on the high voltage resistance.

c) Resistive divider with concentric shield capacitor, *without* interconnection between resistor and capacity (*fig.* 4).

d) As *c*), but *with* interconnection between resistor and capacitor,

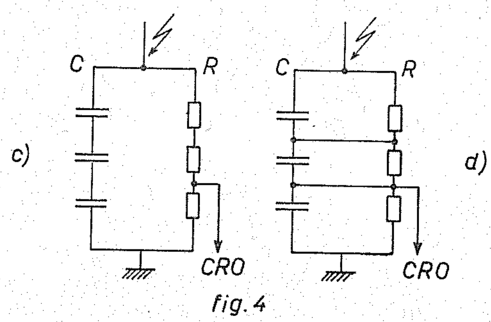

FIG. 4.—Resistive voltage divider with concentric shield capacitor:
a) Without interconnections between resistor and capacity.
b) Resistive and capacitive divider connected in parallel.

so that a resistive and capacitive divider are connected in parallel (*fig.* 4).

e) Capacitive divider.

f) Special divider, e.g. with additional damping.

Investigated parameters.—The primary object of the comparative tests was to determine the *cumulative frequency curves of the breakdown voltage* of the various spark gaps. From these curves, in the first place, values of the 50 % breakdown voltages of the four gaps under examination are obtained. Secondly, the so-called *withstand voltages* ("0 % — voltages") and the "100 % breakdown voltages" can be determined from the cumulative frequency curves. The term "100 % voltage" is just as bad and incorrect as the term "0 % voltage", it should be replaced by a better expression. There

TABLE IV.

C. *Data on cathode ray oscillographs and measuring cables.*

Laboratory	Cathode ray oscillograph									Measuring cable				
	Beam voltage stabil.	Variation in beam voltage about	Divider checked by	Result	C.r.o. calibrated pos. and neg.	Accuracy of oscillograph reading	Cap. of measur. plates	Calibrat. according to	Imp. wave form	Length	Insulation	q Core	q Sheath	Z
		%				%	pF			m		mm²	mm²	Ω
A.E.G.	No	± 1 %	No	—	No	< ± 1 %	30	C.E.I.	1/50	0.8	Polyeth.	0.5	1.5	60
A.S.E.A.	Yes	± 0.5	Yes(1,2)	Good rise time 40...50 mμs	Yes	Voltage ± 0.5 time ± 5	20	Progr.	1/50	10	»	1.5	2.2	45
B.B.C.	Yes	—	No	—	No	2	60...80	C.E.I.	1/50	50	»	3.1	14	71
E.d.F.	Yes	—	Yes(2)	No interfer.	Yes	± 1.5	~ 40	Progr.	1/50	20	»	1.0	5.0	75
E.T.H.	By hand	0.2	No	—	Yes	0.2	50	»	1/50	0	direct connection of divider to c.r.o.			
F.K.H.	No, by hand	± 1	No	—	Yes	± 0.5	40	»	1/50	100	Polyeth.	5	20	56
K.W. Brugg.	No	± 2	Yes (2)	No effect	Yes	± 2	~ 25	C.E.I.	1/50	100	Paper	4	22	37
K.E.M.A.	Yes	—	Yes (3)	Very good	Yes	0.3	10	C.E.I. and Pr.	1/50	10	Polyeth.	2	20	90
Langenthal.	No	?	No	—	No	2	?	C.E.I.	1/50	12	Rubber	1	—	—
Micafil	Yes	—	No	—	Yes	1	20	C.E.I.	1/50	200	»	0.25	5	33
Sécheron	Yes	—	No	—	Yes	0.5	15	C.E.I. and Pr.	1/50	50	»	3	8	33
Siemens	By hand	< 1	Yes (2)	Slight HF interference	Yes	0.5	75	Progr.	1/50	27.5	»	7	4.7	40
Stud. Ges.	Yes	—	Yes (2)	No interference	Yes	0.5	100	Progr.	1/50	31,5	Air	0.3	10	150
T.H. Graz	Yes	—	No	—	Yes	± 1	246	Progr.	1/50	23.25	Amphenol	0.9	3.87	76

(1) Rectangular impulse.
(2) Cable ends short circuited.
(3) Damping check with chopped impulse (*Bull. S.E.V.* 1946, No. 7, p. 177).

is still a lack of clarity about these conceptions introduced by the I.E.C. The simplest method of determining these voltages of 0 to 100 % breakdown frequencies occurs if the cumulative frequency curve is of Gaussian form. This may not be the case. However, provided that the Gaussian distribution applies, the standard deviation s indicates the frequency of all voltages for more than 0 up to less than 100 % breakdown. The value of s can be determined either by calculation using the method of minimum squares or graphically, the various measured values being plotted on so-called probability paper. The system of coordinates on this paper is so chosen that the Gaussian distribution gives a straight line, the inclination of which to the vertical indicates the standard deviation s.

The frequency curves of the breakdown voltages of the four test objects (spark gaps) were determined with a standard 1/50 impulse, both when dry and under rain.

As a second requirement the *breakdown characteristic* of the spark gaps was to be determined. Particular interest attached to the accuracy of the measurement of the breakdown voltage after 0.5 µs, because definite values had been laid down for this by the I.E.C. as regards protective devices.

Methods of measurement.—In order to avoid uncertainties in carrying out measurements with the sphere gap, the following method of measurement was employed: The full (not chopped) test impulses of 1/50 waveform were measured with the cathode ray oscillograph and a resistive voltage divider, the cathode ray oscillograph being calibrated with a direct voltage between 0 and 1,000 V and the ratio of the resistive divider being determined by measuring the values of the resistors.

For the measurement of the chopped impulse voltages it was recommended that in order to calibrate the voltage divider used for this purpose by the laboratory concerned, it should be compared with the resistive divider using full impulses. The procedure adopted in measuring the breakdown frequency curves was laid down as follows. Starting from low voltages, the impulse voltage was increased by small increments until the 100 % voltage was reached, after which it was decreased again in small steps to the voltage corresponding to 0 % breakdown. Ten oscillograms were recorded at each value of the impulse amplitude, from which the value of the relevant impulse voltage and the associated breadkown frequency was determined.

It was further suggested that this measurement should be repeated with exactly the same arrangement of the same test object at an interval of a few weeks in order to get an idea of the reliability of the results obtained by a particular laboratory.

TABLE V.

Schedules to graphs 1 to 20.

Fig. No.	Graph No.	Test object	State of the *spark gap*	Polarity of *the impulses*
5	1	Sphere gap s = 60 mm..........	Dry	Positive
6	2	—	Dry	Negative
7	3	— s = 125 mm...........	Dry	Positive
8	4	—	Dry	Negative
9	5	Rod-rod gap.....................	Dry	Positive
10	6	—	Dry	Negative
11	7	Rod-plane gap	Dry	Positive
12	8	Rod-plane gap.....................	Dry	Negative
13	9	Sphere gap s = 60 mm...........	Wet	Positive
14	10	—	Wet	Negative
15	11	— s = 125 mm...........	Wet	Negative
16	12	—	Wet	Negative
17	13	Rod-rod gap.....................	Wet	Positive
18	14	—	Wet	Negative
19	15	Rod-plane gap	Wet	Positive
20	16	—	Wet	Negative
21	17	Impulse characteristic $u = f\,(t_a)$	Dry	Pos. and neg.
22	18	— — —	Wet	Pos. and neg.
23	19	Deviation of all spark gaps	Dry and wet	Pos. and neg.
24	20	Frequency of the 50 % values	Dry	Pos. and neg.

TABLE VI.

Comparative Tests on Gaps.

Summary of the *mean values of the* 50 % *flashover impulse voltage* of the four types of spark gaps investigated, derived from the 50 % values furnished by the participating laboratories.

Spark gaps	Polarity	I.E.C.	Dry	Under rain
		kV	kV	kV
Sphere gap 60 mm...........	+	162	162.5 (10)	159.9 (6)
	—	161	161.3 (10)	162.8 (6)
Sphere gap 125 mm...........	+	298	306.8 (11)	255.3 (6)
	—	282	278.0 (11)	270.7 (6)
Rod-rod gap 450 mm..........	+	—	291.7 (13)	293.0 (8)
	—		377.8 (13)	369.1 (7)
Rod-plane gap 450 mm.........	+	—	243.9 (11)	243.1 (6)
	—		515.7 (8)	432.0 (4)

NOTE.—The figures in brackets indicate the number of laboratories involved in the derivation of the mean value.

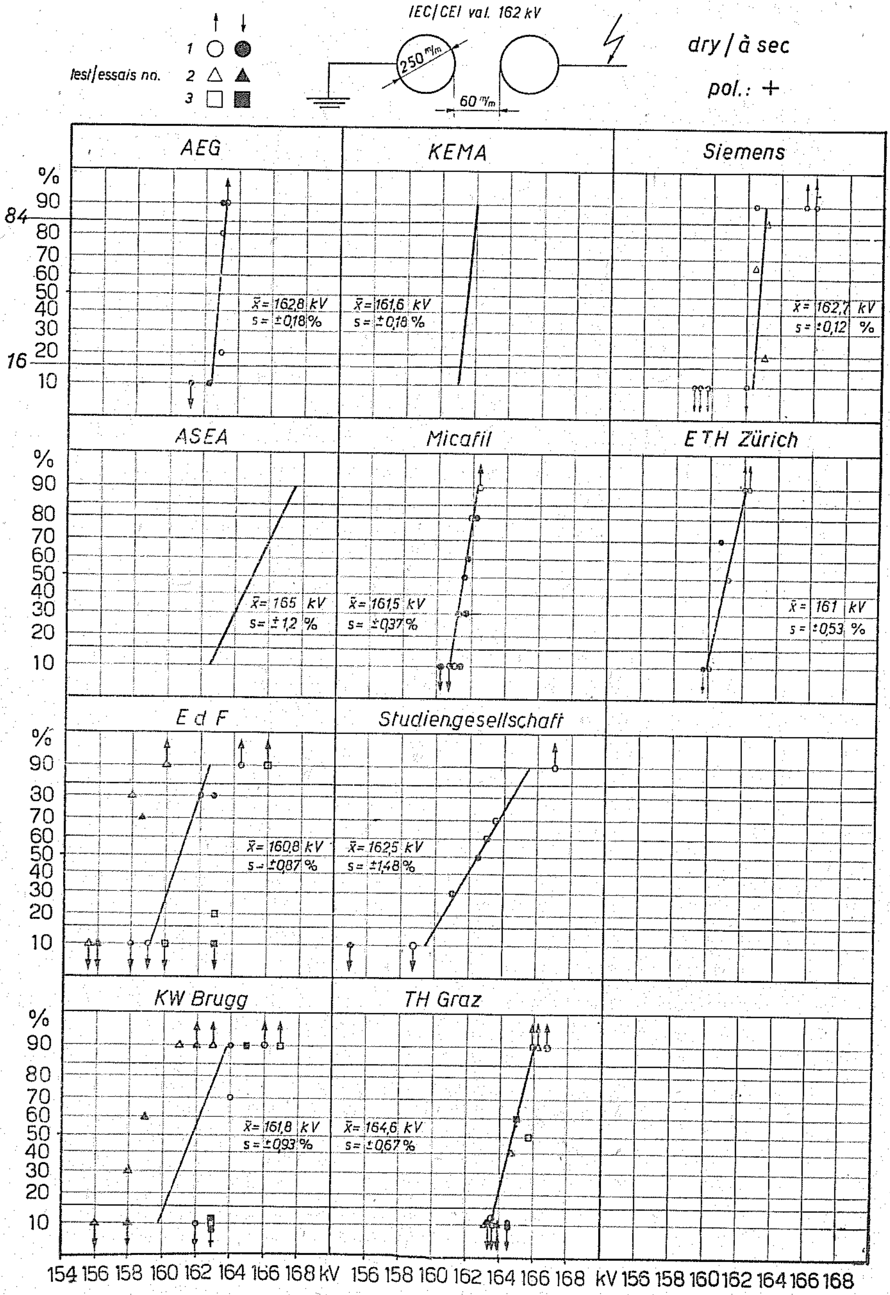

Fig. 5.—Results of sphere gap, $s = 60$ mm, dry, positive polarity. (Graph No. 1.)

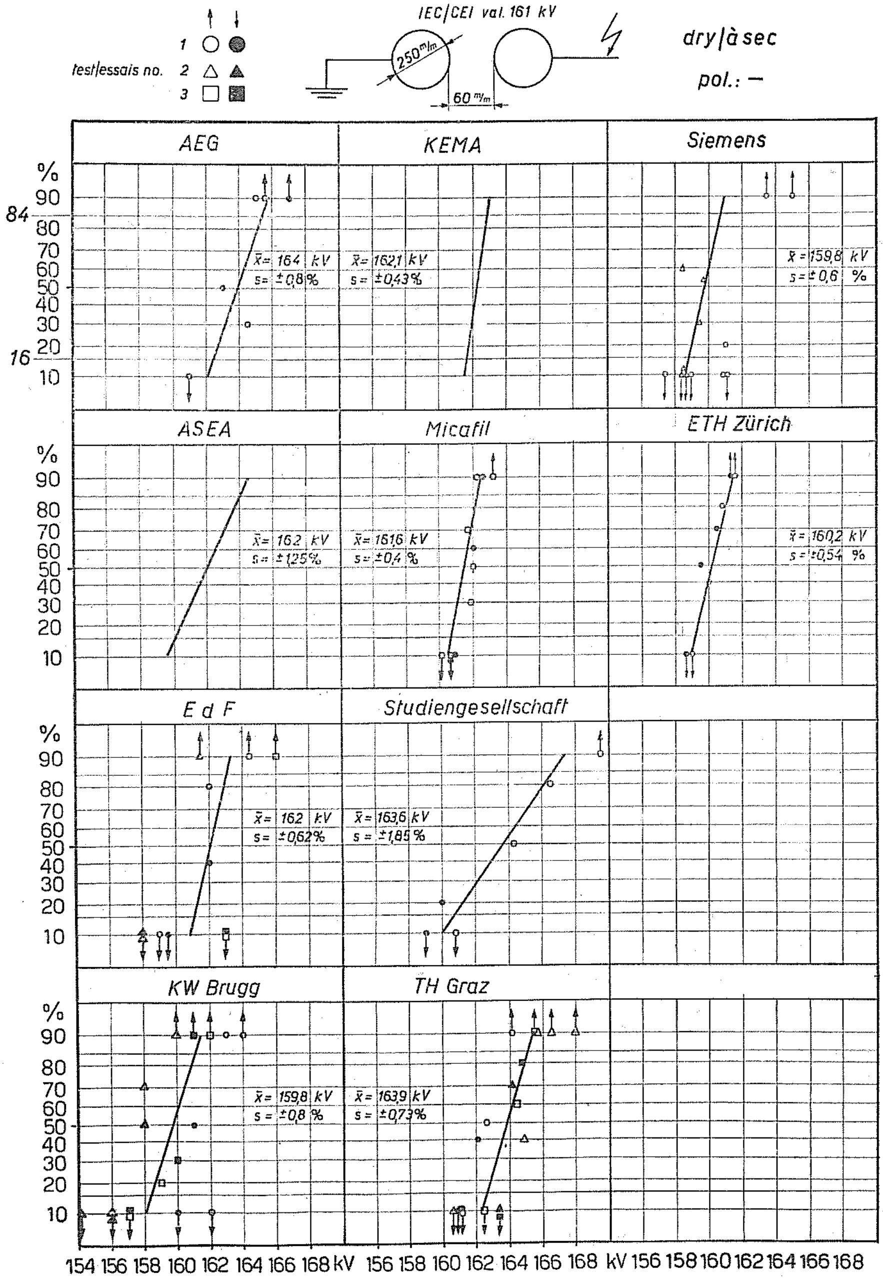

FIG. 6.—Results of sphere gap, $s = 60$ mm, dry, negative polarity. (Graph No. 2.)

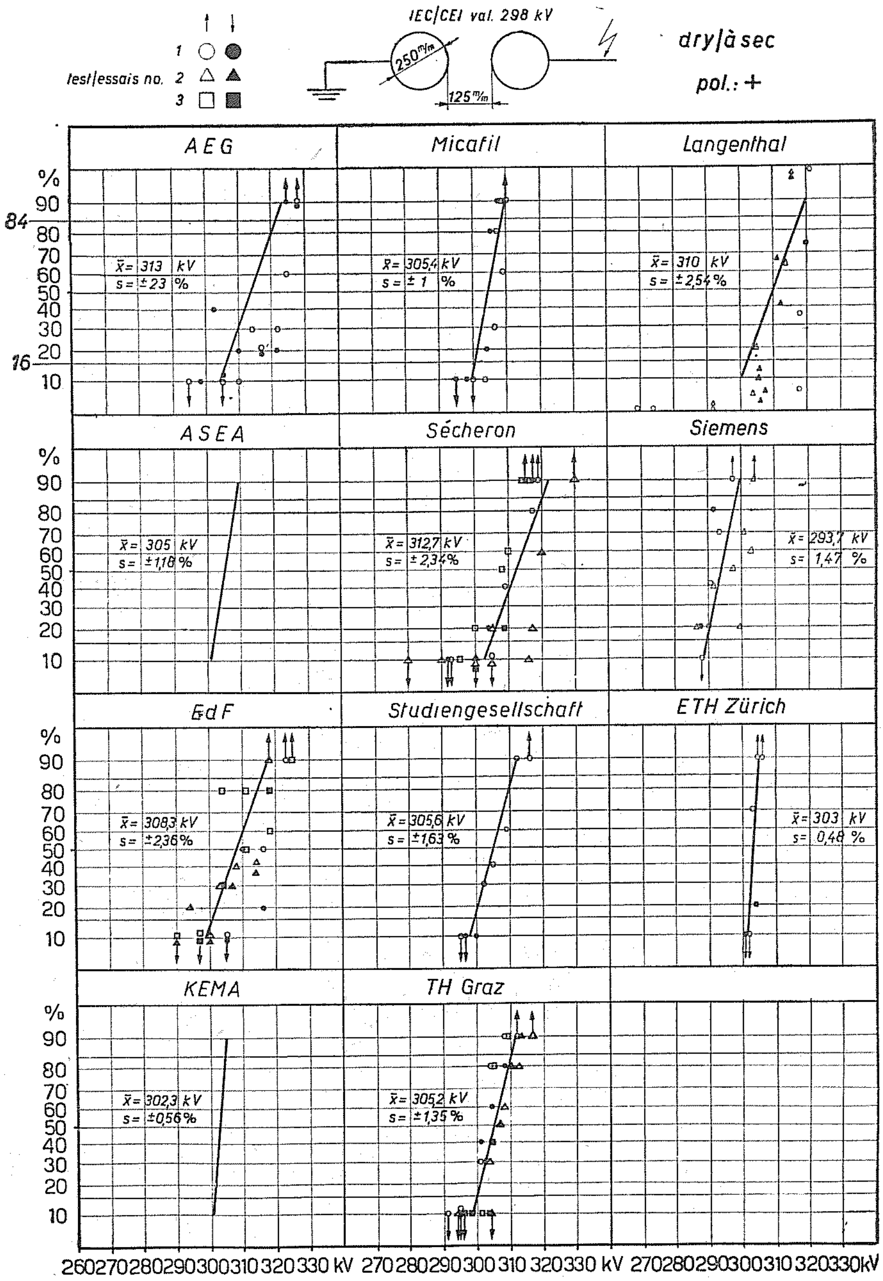

FIG. 7.—Results of sphere gap, $s = 125$ mm, **dry**, positive polarity. (Graph No. 3.)

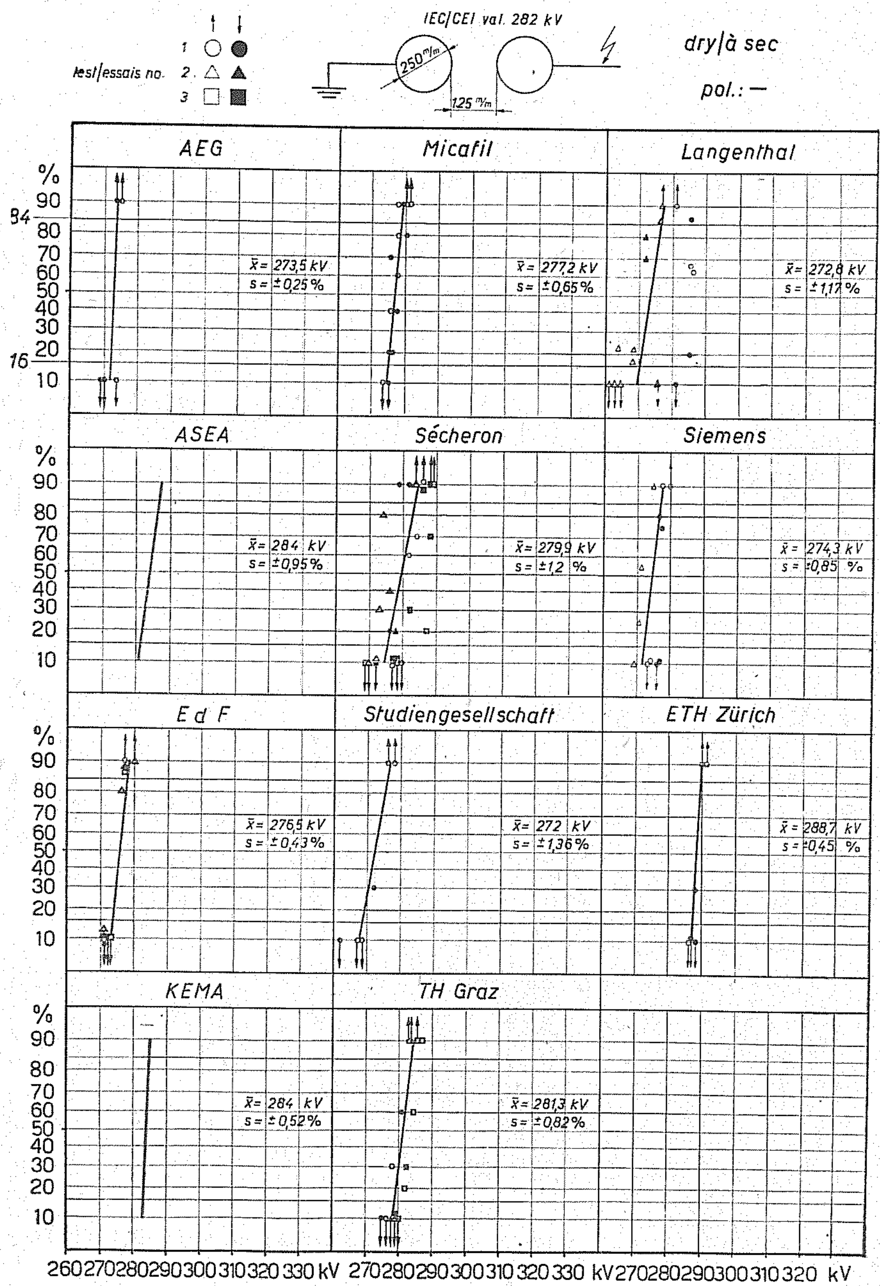

Fig. 8.—Results of sphere gap, $s = 125$ mm, dry, negative polarity. (GraphNo. 4.)

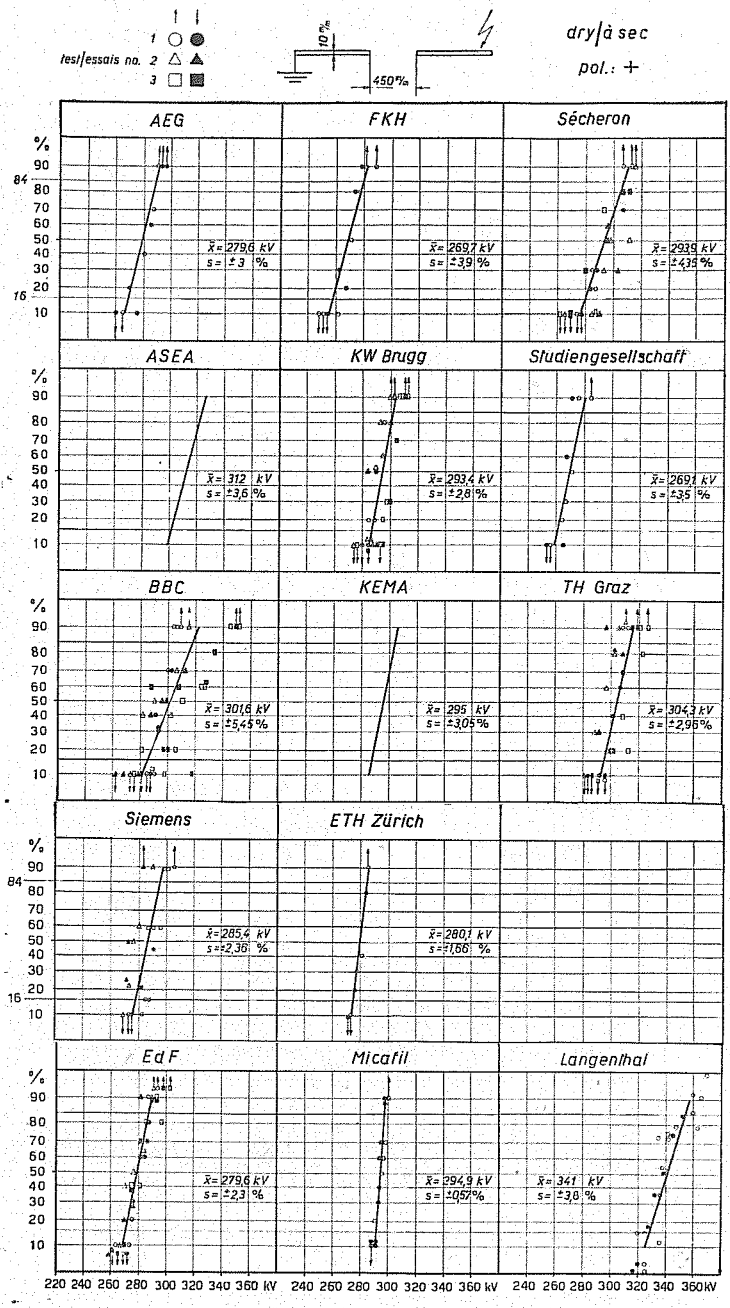

FIG. 9.—Results of rod-rod gap, dry, positive polarity. (Graph No. 5.)

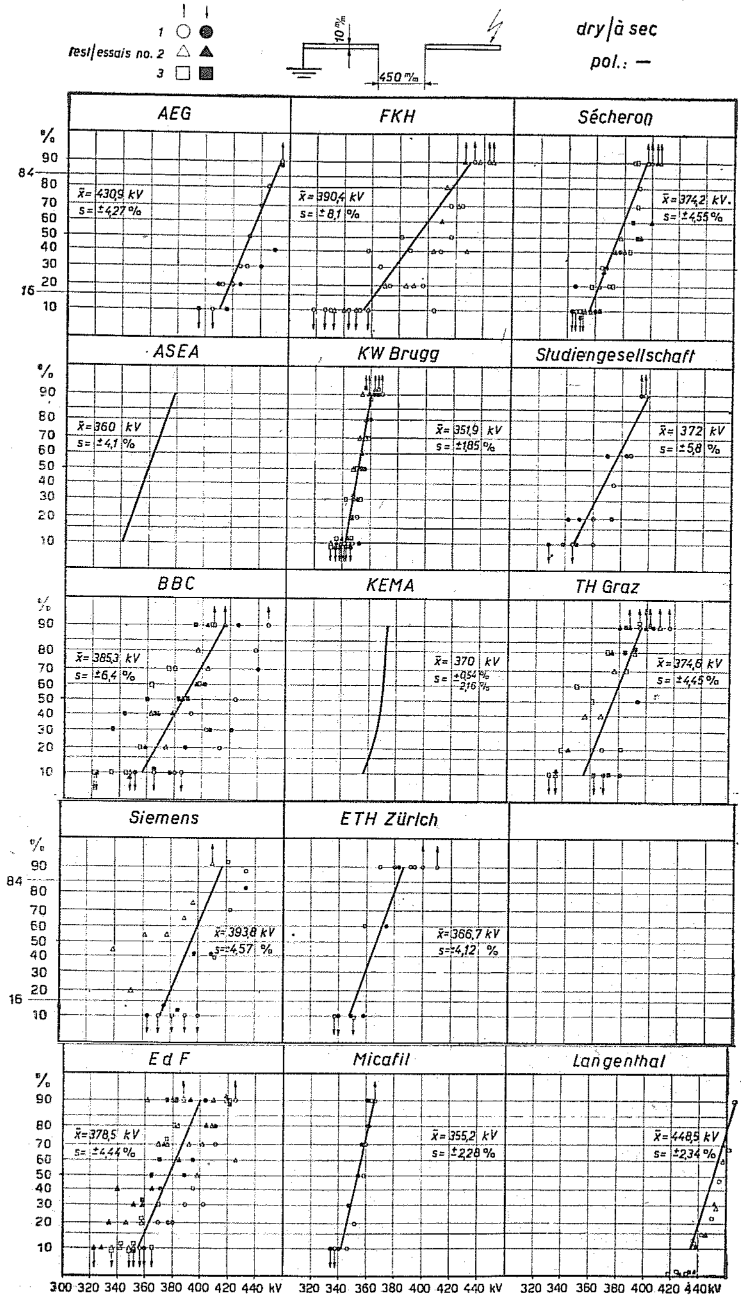

FIG. 10.—Results of rod-rod gap, dry, negative polarity. (Graph No. 6.)

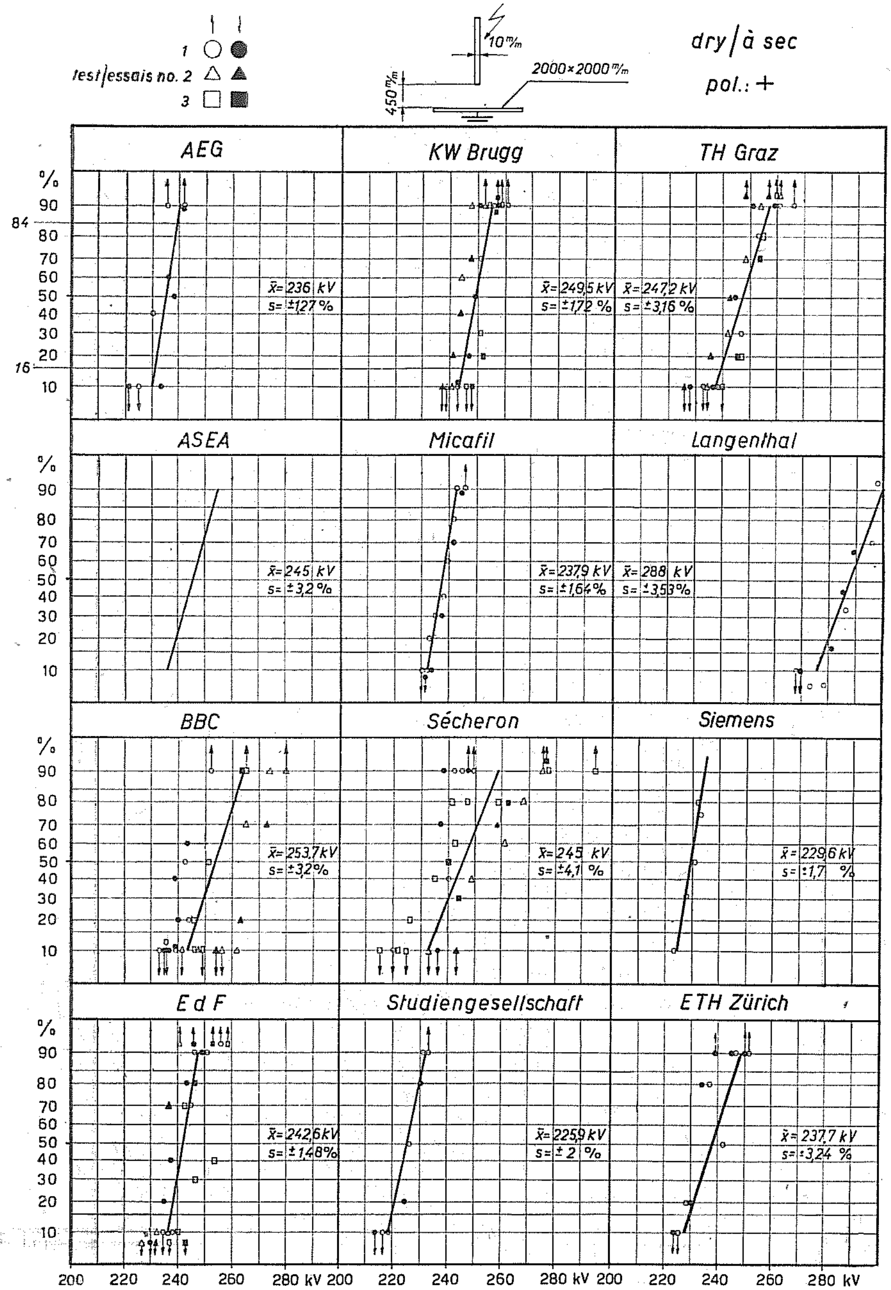

FIG. 11.—Results of rod-plane gap, dry, positive polarity. (Graph No. 7.)

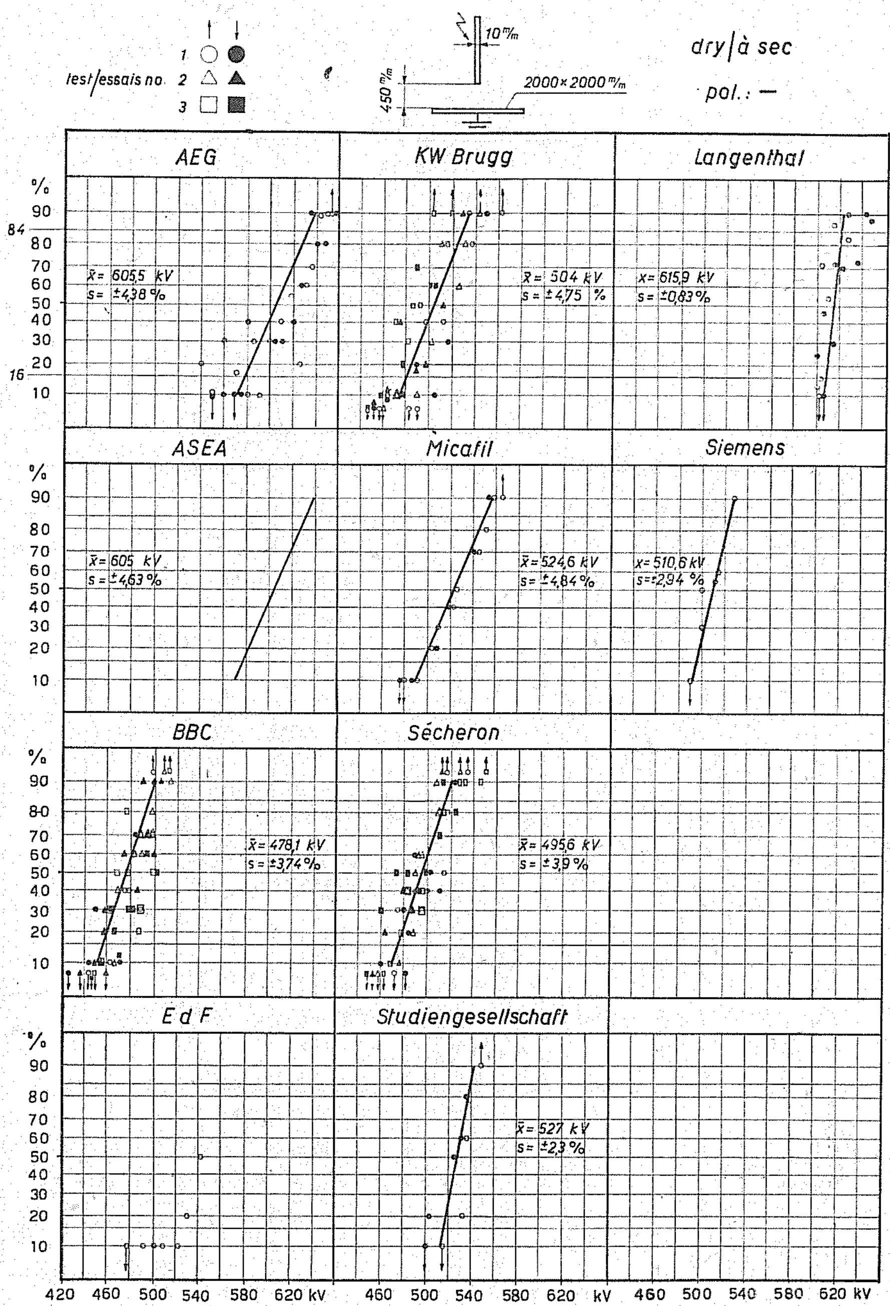

Fig. 12.—Results of rod-plane gap, dry, negative polarity. (Graph No. 8.)

Results of measurements.—The results sent in by the various laboratories for the values of the breakdown voltage were first reduced to normal atmospheric pressure (760 mmHg/20° C) and then plotted on the graphs Nos. 1 to 18 (*figures* 5 to 22). Of these, graphs 1 to 16 show the cumulative frequency curves on probability coordinates, and graphs 17 and 18 the breakdown characteristics measured by the various laboratories. The significance of each of the graphs 1 to 18 is indicated in Table V. Each 50 % breakdown voltage was deter-

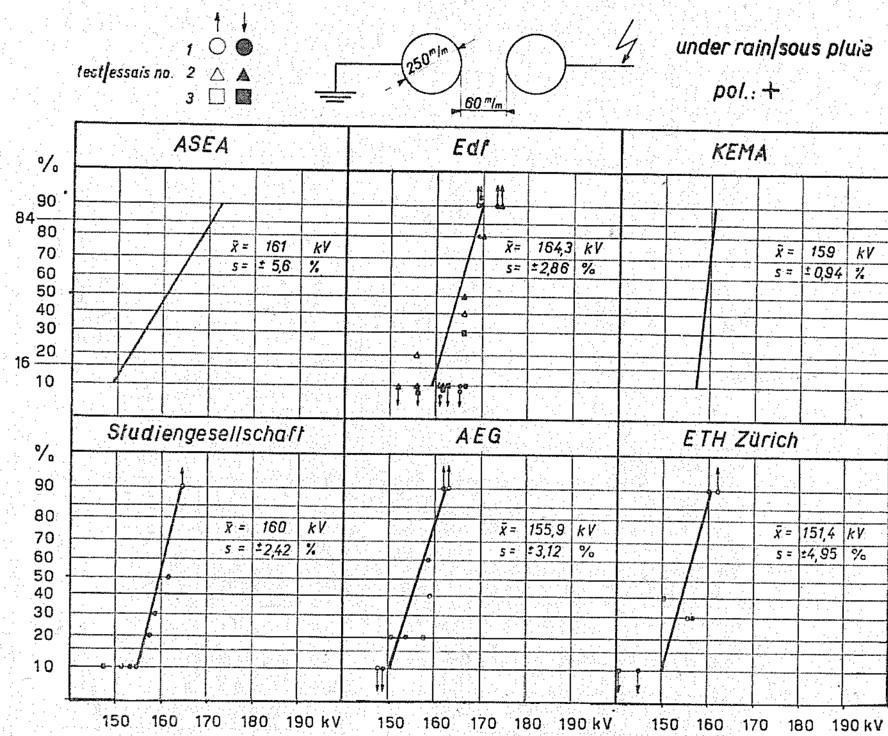

FIG. 13.—Results of sphere gap, $s = 60$ mm, wet, positive polarity. (Graph No. 9.)

mined graphically by drawing the Gaussian straight line in the most probable position through the clusters of points corresponding to all measurements. The standard deviation *s* was determined from this straight line by reading off the values of the voltage corresponding to 16 % and 84 % breakdown frequency respectively.

Table VI shows the overall average values, based on all the laboratory measurements, for the 50 % breakdown voltages of the four spark gaps investigated. Weighted averages are involved, in that every measuring point has been taken between 10 % and 90 % breakdown values. In the case of the rod-rod and rod-plate gaps the results obtained by one of the laboratories (P.L.) have not been taken into account, as they are doubtful. These values have nevertheless been taken into account in graphs 3 to 8 (*fig.* 7 to 12).

The I.E.C. values for the breakdown of sphere gaps are shown in the table for comparison with the average measured values. The figures given in brackets after the measurement values indicate the

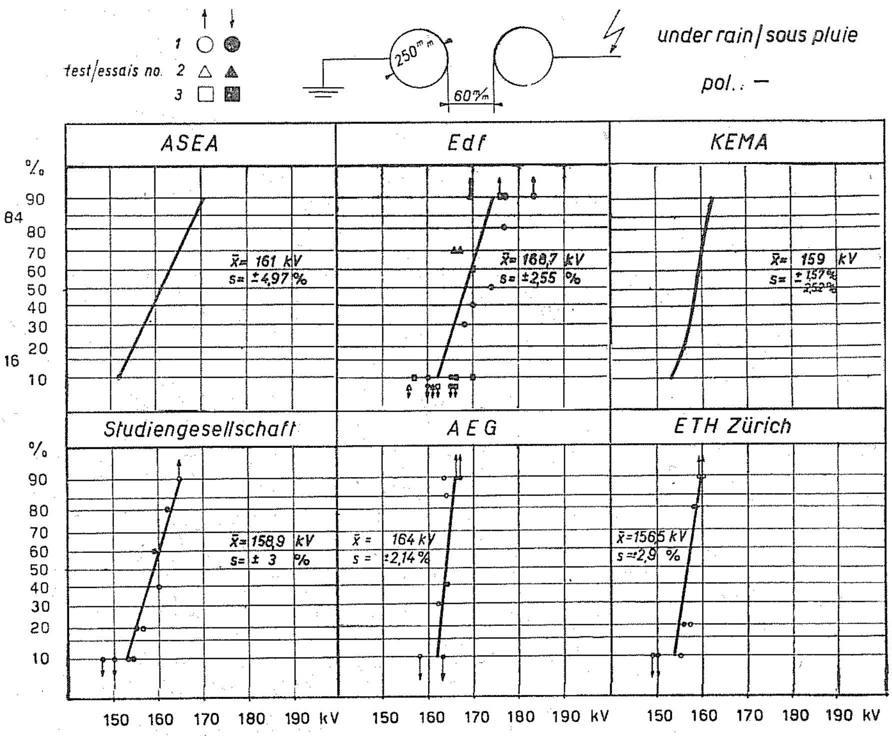

FIG. 14.—Results of sphere gap, s = 60 mm, wet, negative polarity. (Graph No. 10.)

number of the laboratories which have taken part in the relevant measurement.

The Gaussian deviation *s* has been indicated on graph 19 (*fig.* 23) in decreasing values for the various laboratories. Each laboratory has been indicated by a letter symbol. The meaning of these symbols is given in the description and in Table I.

Similarly, the group frequency of the values measured by the separate laboratories for the 50 % breakdown voltage has been shown on graph 20 (*fig.* 24).

Discussion of the present results.—Consideration of the results of the measurements shows firstly that for the *sphere gap* in the dry

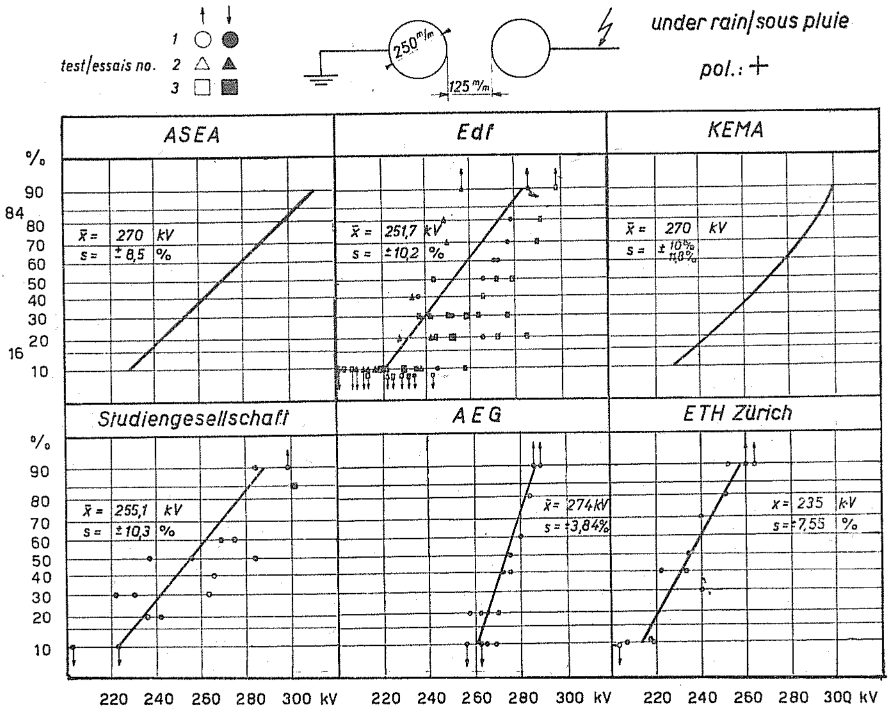

FIG. 15.—Results of sphere gap, $s = 125$ mm, wet, negative polarity. (Graph No. 11.)

condition the 50 % breakdown values for a 60 mm gap differ from the I.E.C. values by less than 1 %. On the other hand, the values for a 125 mm gap (gap = radius of sphere) differ from the I.E.C. values by + 3 % with a positive impulse and almost — 1,5 % with a negative impulse. This agreement can be regarded as satisfactory, but it must be borne in mind that measuring errors of 3 % must be reckoned with using sphere gaps.

The results obtained by different laboratories differ very little from one another for the sphere gap (*fig.* 24). All the average values of the 50 % breakdown voltage lie within a band of 5 kV or ± 1,5 % for the 60 mm gap and 25 kV or ± 3,5 % for the 125 mm gap for this type of spark gap. Thus it may be said that the measured values obtained for the full 1/50 impulse amplitudes using a resistive divider and cathode ray oscillograph on the one hand a sphere gap on the other are mutually comparable to a degree of accuracy which is generally sufficient for industrial purposes.

In the case of the results obtained for the *arrangements with a non-homogeneous electric field* in the dry condition (rod-rod and rod-plate gaps) the differences in the measured values obtained by

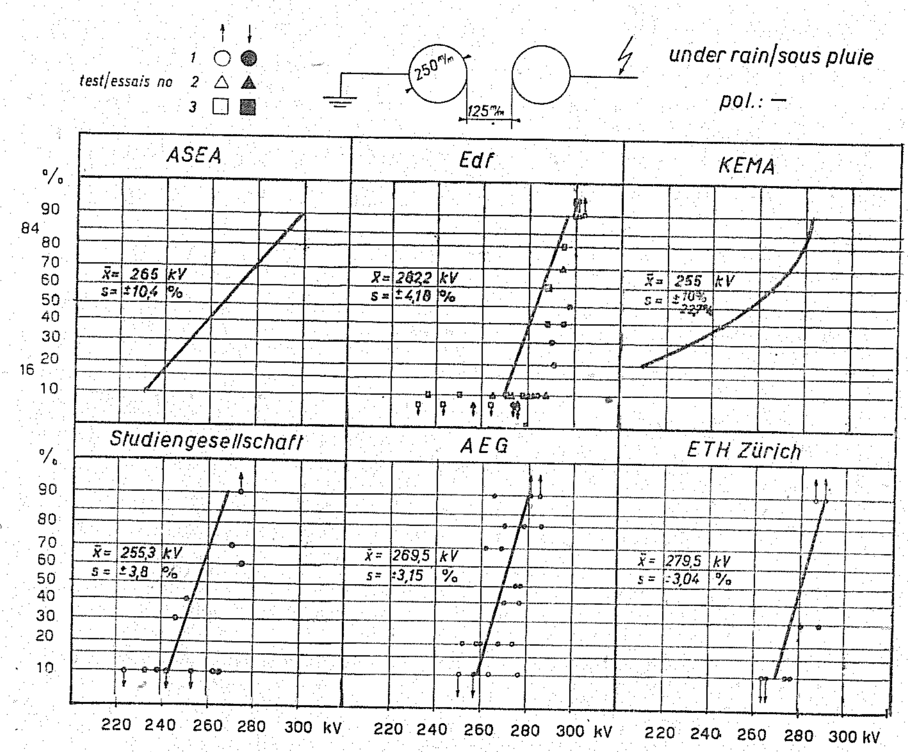

FIG. 16.—Results of sphere gap, $s = 125$ mm, wet, negative polarity. (Graph No. 12.)

the various laboratories are considerable; as shown in *figure* 24, all the values lie within ± 10 % for rod-rod gaps and ± 6 % and ± 15 % for a positive and negative impulse respectively for rod-plate gaps. An attempt was made to effect an improvement by inserting an additional correction for the humidity, as suggested by the I.E.C. for insulators.

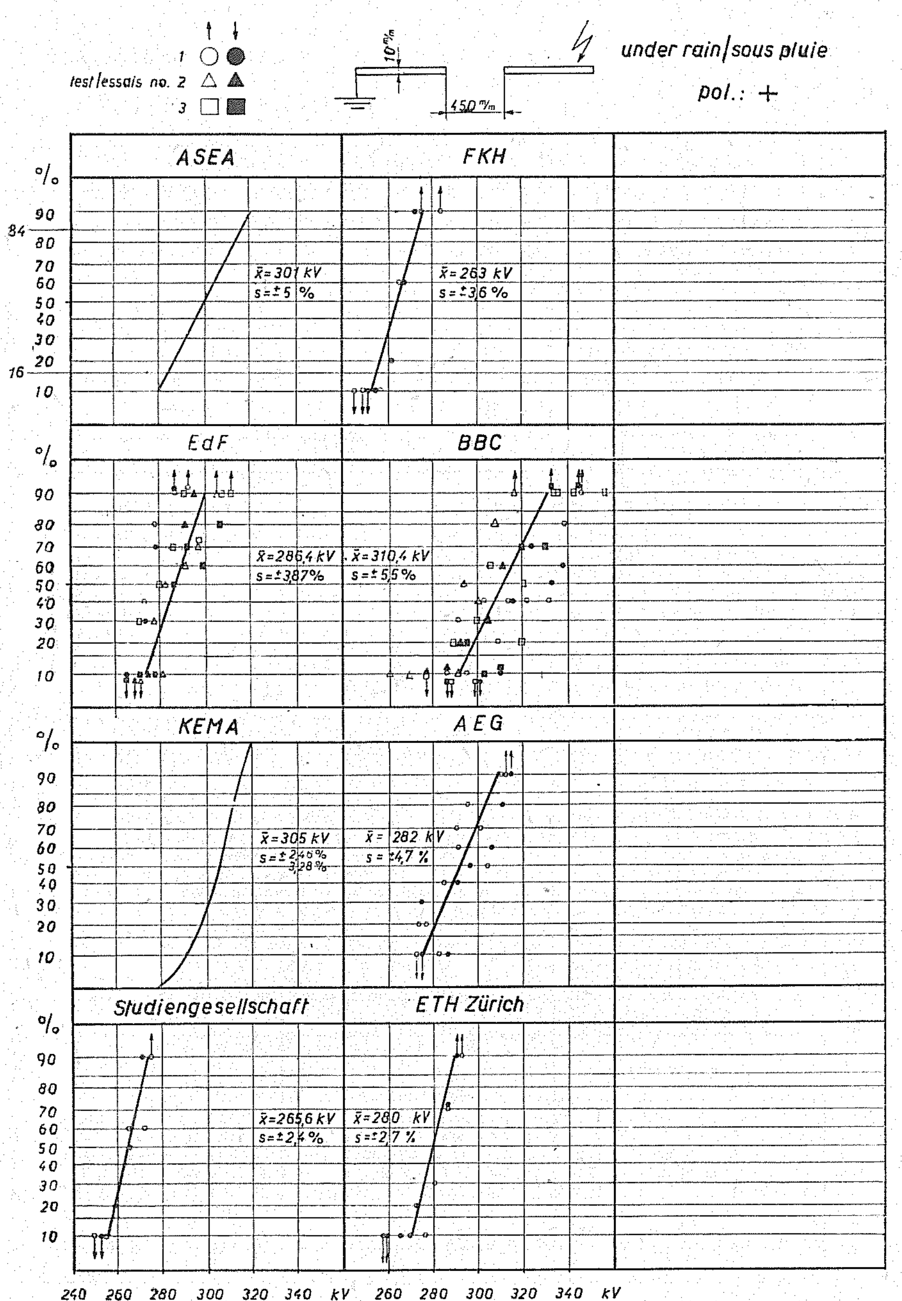

FIG. 17.—Results of rod-rod gap, wet, positive polarity. (Graph No. 13.)

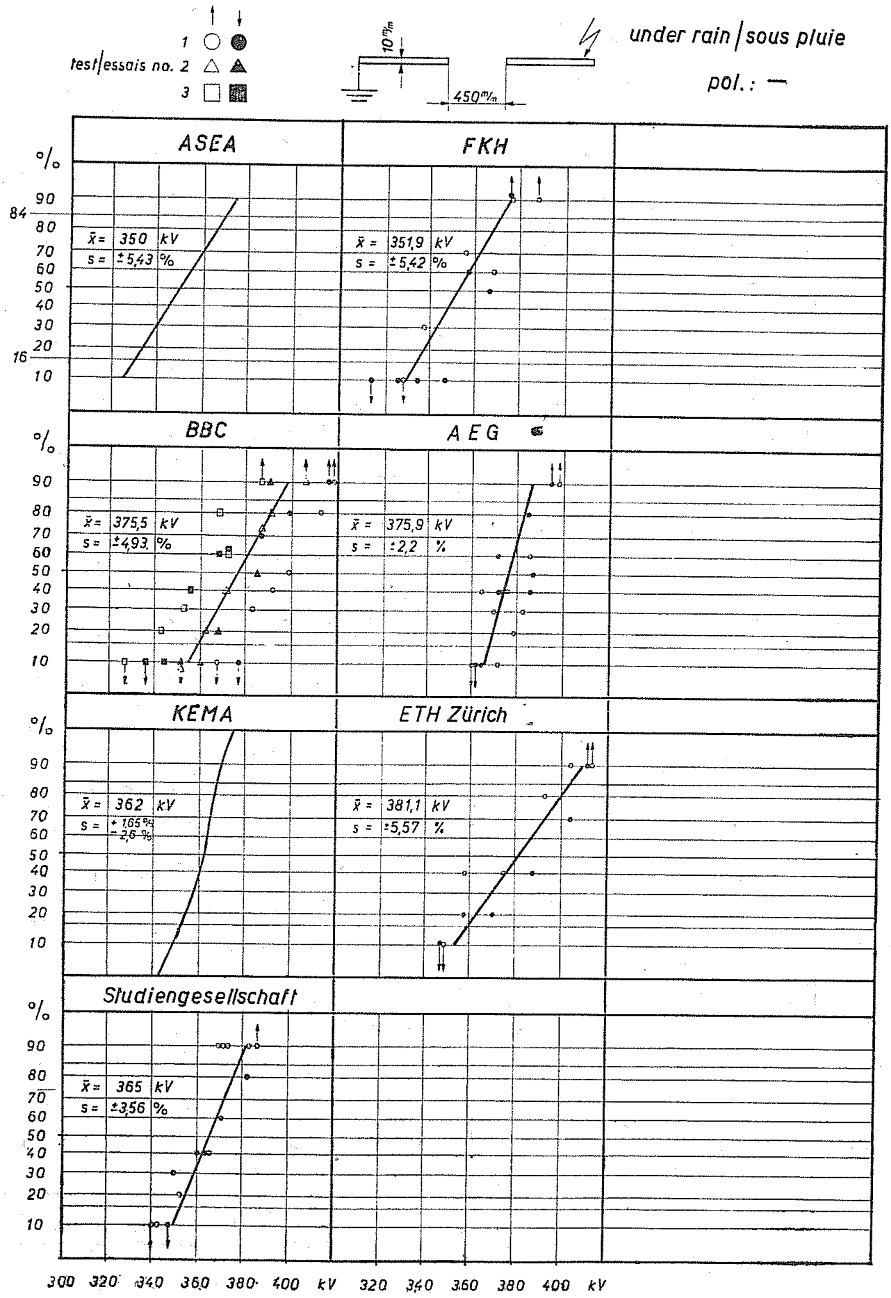

FIG. 18.—Results of rod-rod gap, wet, negative polarity. (Graph No. 14.)

However, no significant improvement was obtained. Therefore it was thought preferable to apply a correction for the atmospheric pressure only to the measured values, the values of the atmospheric humidity existing during the measurements being specified separately.

A very striking observation, which is of practical significance, is that the frequency curves of exactly the same arrangement, mea-

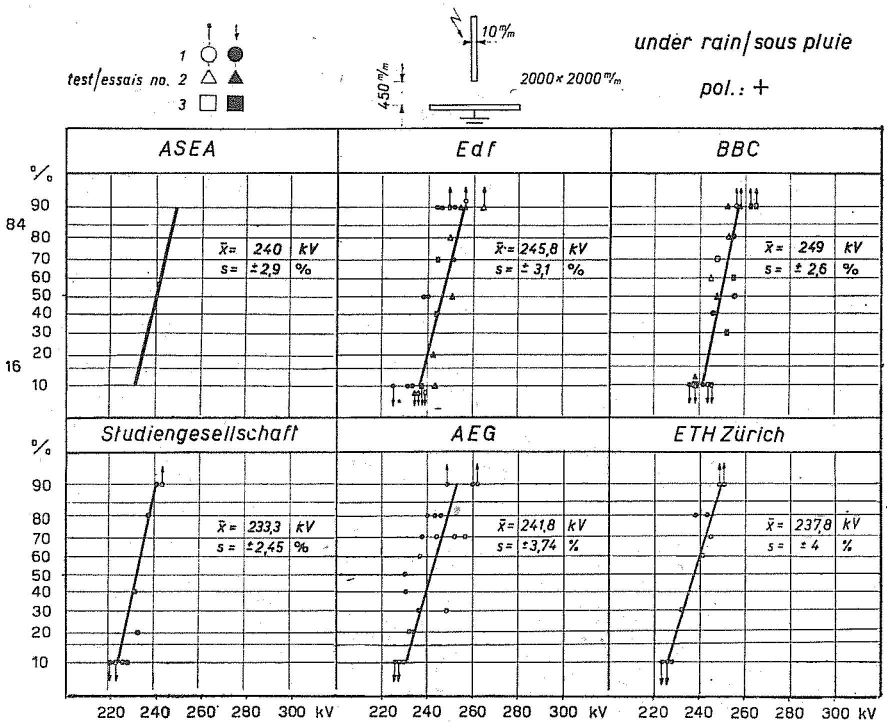

FIG. 19.—Results of rod-plane gap, wet, positive polarity. (Graph. No. 15.)

sured on different days, do not coincide, but may be separated by a distance which is some times greater than the value of the standard deviation of measurements taken on the same day. Differences of 5 to 9 % in the 50 % voltages were reported by individual laboratories. Bearing in mind that the 50 % values are best defined mathematically as the values at the intersection of the 50 % horizontal line with the probability curve (neither the 0 % nor the 100 % values can, as asymptotes, be defined mathematically), this result can only be explained by the fact that *certain effects influence the breakdown* *voltages of these spark gaps, which are at present not taken into account.* The magnitude of this uncertainty, which cannot reside in the measurement because it would otherwise also show itself in the measurements with the sphere gap, is so considerable that it is of importance in the coordination of insulation. This range of uncertainty must be regarded as an additional voltage increment when grading insulation if the grading is to result in reliable operation. The expla-

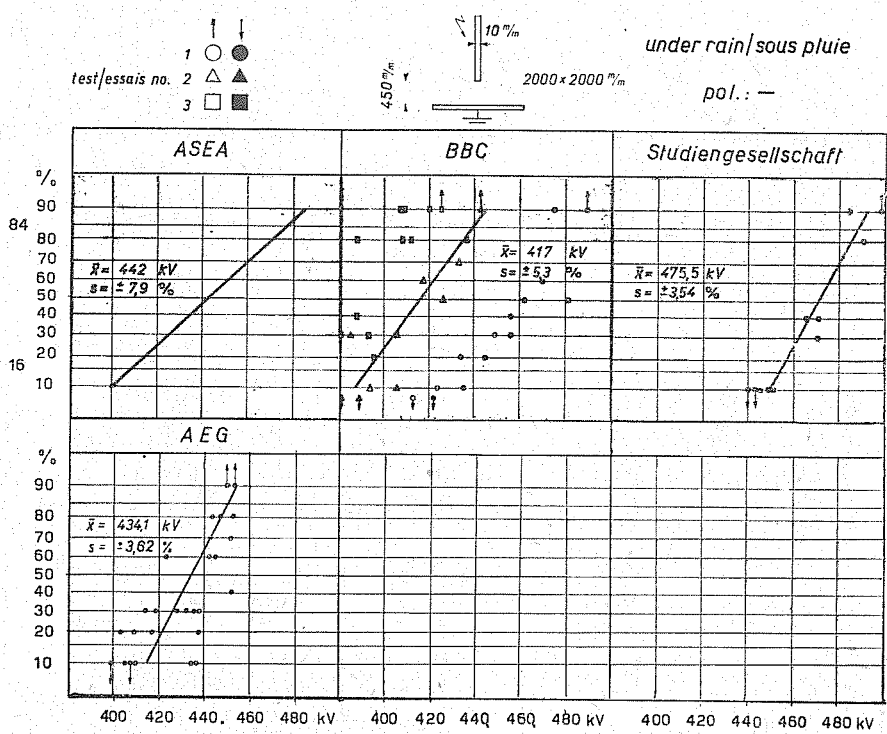

FIG. 20.—Results of rod-plane gap, wet, negative polarity. (Graph No. 16.)

nation of the variation in the frequency curves in terms of days, weeks and months is therefore of practical importance. Similar variations have already been found in previous comparative test (1).

(1) I.E. Allibone, Intern. Comparison of Impulse-Voltage-Tests, J.I.E.E., London, December 1937. K. Berger, *Bull. A.S.E.* 1953, No 8, «Recherches expérimentales sur la dispersion des tensions de contournement et d'amorçage d'isolateurs, éclateurs et parafoudres soumis à de fortes tensions de choc».

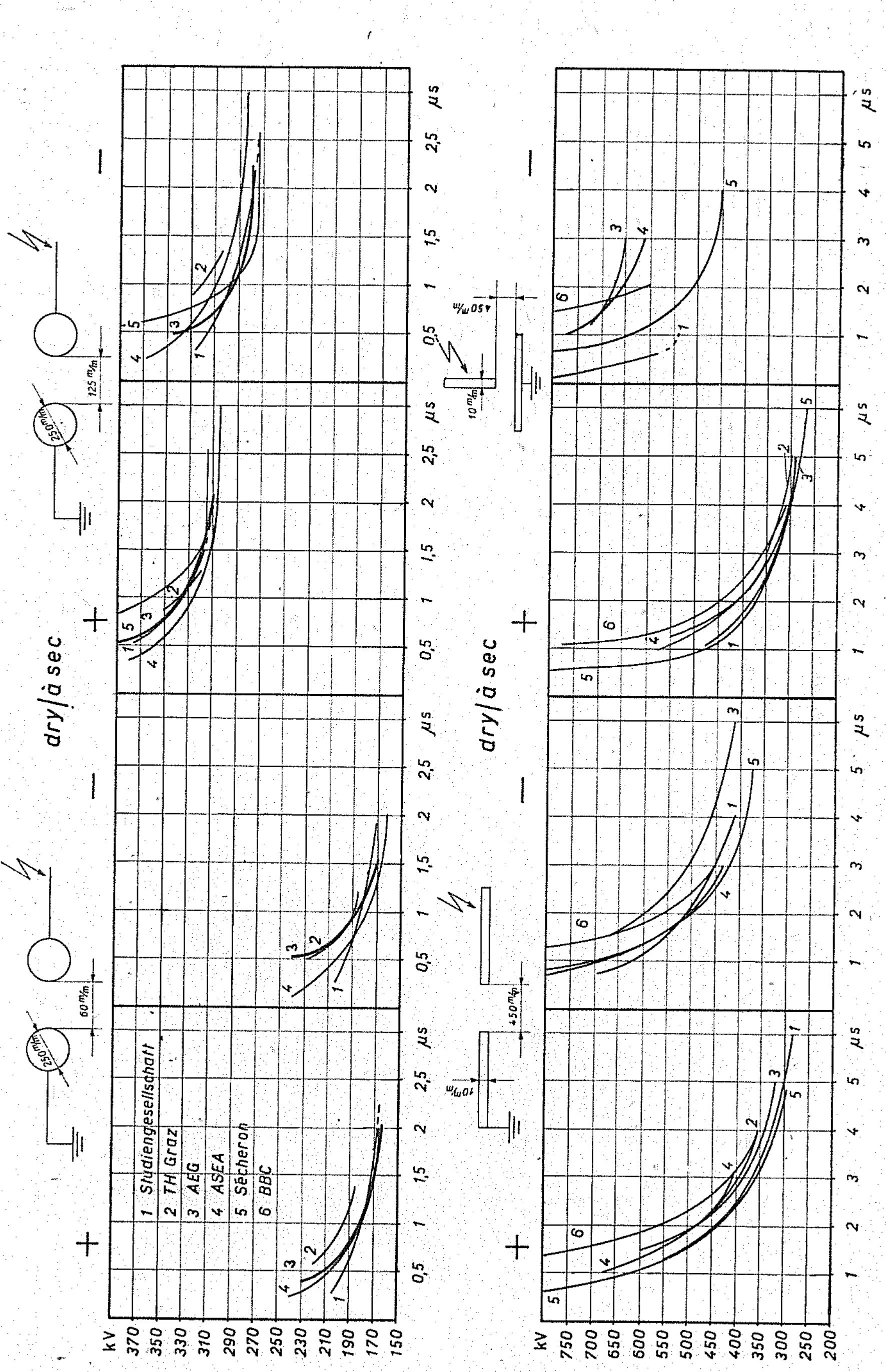

FIG. 21.—Impulse characteristic $u = f\ (tä)$, dry, positive and negative polarity.
(Graph No. 17.)

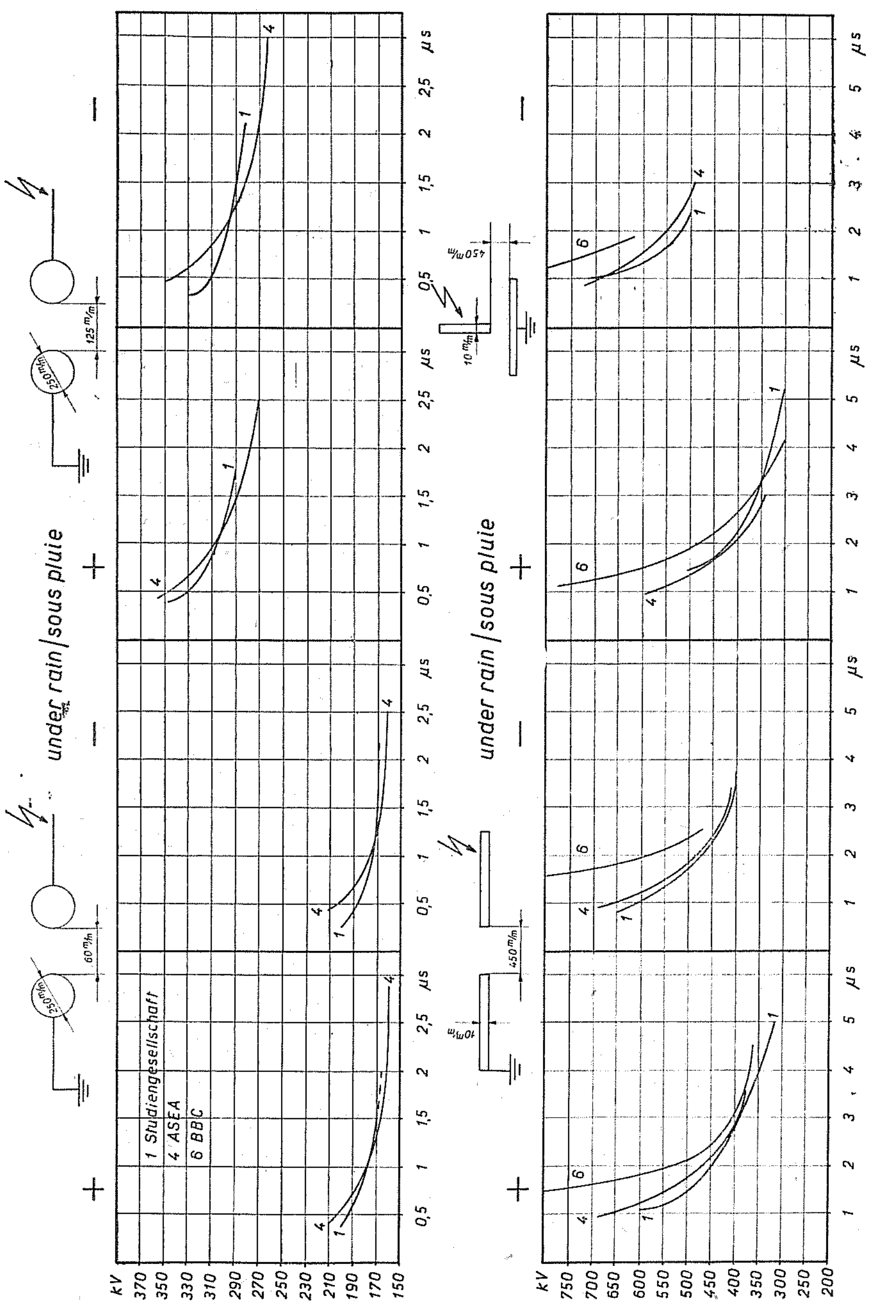

Fig. 22.—Impulse characteristic $u = f\ (t_{ü})$, wet, positive and negative polarity. (Graph No. 18.)

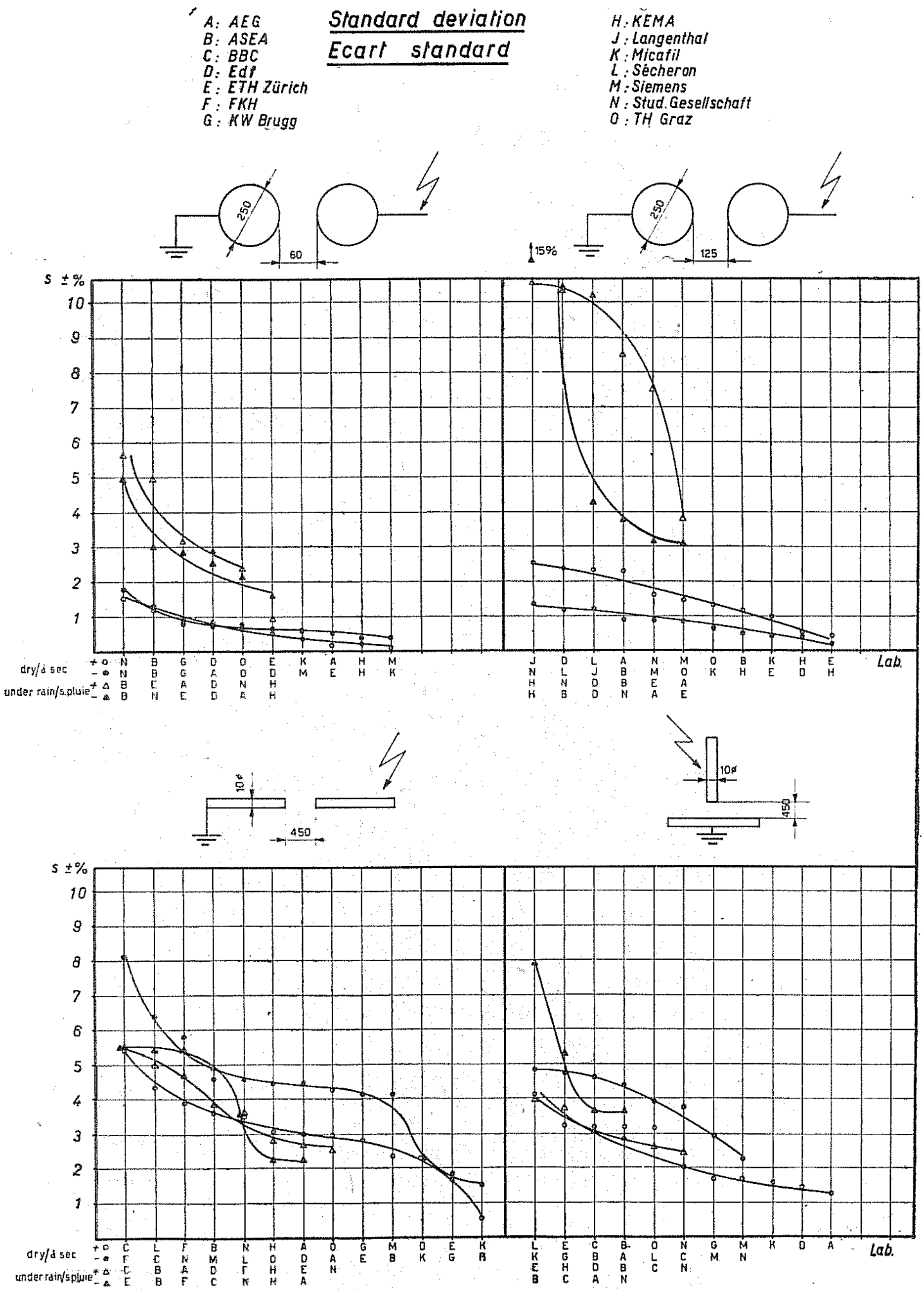

Fig. 23.—Deviation of all investigated spark gaps, dry and wet, positive and negative polarity. (Graph No. 19.)

In 1937 it was believed that they were attributable to uncertainties in the impulse measurements. But this explanation can no longer be entertained in the light of modern measuring techniques, as the results of the sphere gap measurements show. The fluctuations in

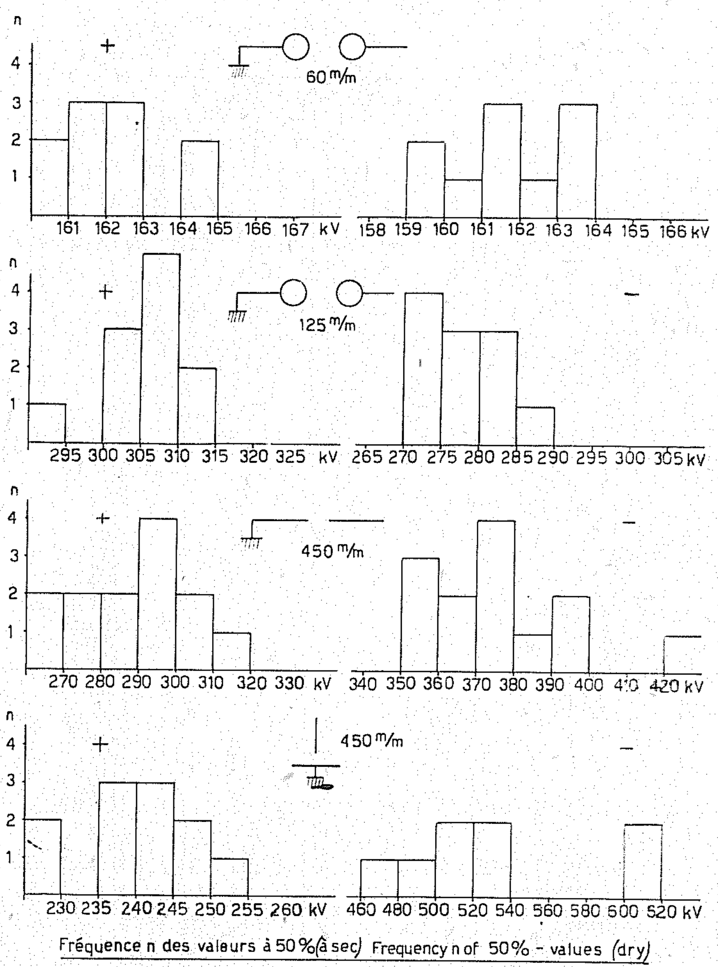

FIG. 24.—Frequency of the 50 % values, dry, positive and negative polarity. (Graph No. 20.)

the breakdown voltages in the non-homogeneous eld, which are, so far, explicable, were discussed at a meeting of all the technical personnel of the Study Group held on 18/19 November, 1955 in

Zurich. They also constituted the reason for including fully detailed information in Tables II to IV on all the laboratory arrangements. So far, however, it has not been possible to find any definite effect which would explain the large variations.

The present report must therefore confine itself to establishing the existence of an uncertainty, not of the impulse measurements, but of the behaviour of rod-rod and rod-plate spark gaps, and to raising the question of the origin of the variations in the frequency curves, which have now been definitely established.

Since it is to be expected that at least equally large variations also occur with insulators, the fields of which are, of course, similar to those of the spark gap systems described above, it is important in practice to have an explanation of the phenomenon, or where this is not possible, at least to take the phenomenon into account.

The *effect of rain* varies very widely for the different spark gaps. It is interesting to note that rain has little effect on the *sphere gap* with a 60 mm gap, whereas with a gap of 125 mm a considerable reduction (of the order of 20 %) was found for a positive impulse. In this case the frequency curve can no longer be of Gaussian form, because the deviations become much larger in the downward direction than in the upward direction, which means that the distribution is assymetrical. Correspondingly curved graphs were produced by two laboratories. The slight effect of rain with the small gap distance is presumably due to the fact that there are no drops of water on or between the spheres at the instant when the impulse is applied. With a larger number of pulses an effect would be bound to show. In the case of the *rod-rod gap* the effect of rain is vanishingly small. With the *rod-plate gap*, the presence of rain brings about a reduction in the very high voltage for a negative impulse, and a smaller increase in the breakdown voltage for a positive impulse.

As opposed to the results of the sphere gap, the observations with the non-homogeneous arrangements can be understood. The fact that the rod-rod gap is unaffected by rain is of practical importance.

Finally, reference should be made to the measurements of the *breakdown voltage on the wavefront* in accordance with curves of the graphs No. 17 and 18 (*fig.* 21 and 22). In this connection the point with an abscissa value of 0.5 μs is of particular importance, because this is the point for which measurements are required by the I.E.C., e.g. for protective devices. In contrast to the measurements taken with the full 1/50 impulse, difficulties are encountered in the measurement itself. Variations of 20 to 30 % in the breakdown voltage measured at the 0.5 μs point with sphere gaps and similar or greater variations even at the 1 μs point with the rod-rod gap are by no means rare, as is shown in *figure* 21. The discussion in the Study Group has shown that there is a need for a reliable and simple method of checking the voltage divider and cathode ray oscillograph used for these measurements. Until this point has been cleared up, the specification of the breakdown voltages on the wavefront is more or less unreal, because they depend greatly on the measuring arrangement employed. This second problem, too, merits the attention of the C.I.G.R.E., especially of the high voltage laboratories which are directly concerned.

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